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ASSESSMENT OF COLOR AS A SONAR DISPLAY PARAMETER.(U)
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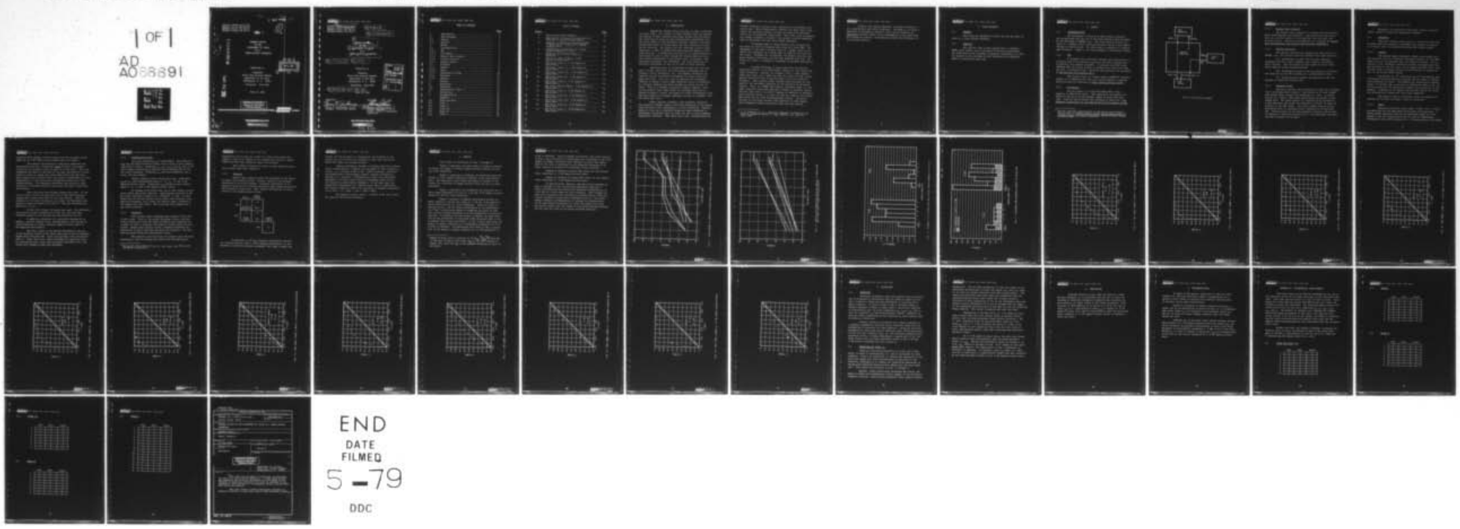

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Contract N00024-67-C-1461
Project Serial SF0010316
TRACOR Project 002 039 01
Document Number 68-766-U

LEVEL II

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SUMMARY REPORT
ON THE
ASSESSMENT OF COLOR
AS A
SONAR DISPLAY PARAMETER

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Submitted to

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Naval Ship Systems Command
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Contract N00024-67-C-1461
Project Serial SF0010316
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SUMMARY REPORT ON THE ASSESSMENT OF COLOR AS A SONAR DISPLAY PARAMETER

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14 TRACOR-68-766-U

June 25, 1968

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1. INTRODUCTION

Significant advances have been made in sonar technology in recent years. As a result of these advances both the quantity and quality of data available from sonar systems have increased. The extraction of detection and classification information from the large volume of data available, however, remains a difficult problem which must be solved before the full potential of sonar can be exploited. One logical and very necessary area of study, therefore, is that of information processing and display to the sonar operator. A correlative necessity is to explore methods of increasing the flow of data through the display-operator interface without degradation of performance and, if possible, with increased performance and efficiency. One such method for exploratory development is the use of color in sonar displays.

Experimentation of considerable breadth has, over the last 15 years, shown that for every sensory continuum such as loudness, pitch, brightness, etc., the maximum information an observer can use in absolute recognition is almost never more than three bits. That is to say, an observer can accurately identify a maximum of about eight different levels of brightness on a display ranging from white through six levels of grey to black. This is a somewhat optimistic estimate, however, since, if one presents these eight levels in a display which has no ordered scaling of levels, the number of levels discriminable with any great degree of certainty decreases to four or, perhaps, five, and often only three.

Color, however, presents a very different situation. The operator's dynamic range in the color dimension is far greater than that with Z-axis brightening or Y-axis deflection. Whereas physical color can be described along the single dimension of wavelength, perceptual color is really the sum of three somewhat independent receivers. This three color code, differentiated by

retinal chemicals, permutes into a multitude of discernibly different hues. Recent experimental evidence has shown that if the colors are properly selected, as many as twenty-four different colors can be absolutely identified.* Thus color, when considered as a single parameter, presents a far greater receiver bandwidth than is achievable with any other single dimension.

An analogy might be drawn between color reception by the human eye and the red-green-blue triad of a color CRT. The impingment of the three electron beams on a single triad is not unlike the impingment of a single spot of light on the fovea of the retina. Although the red phosphor can produce only red, the green phosphor only green, and the blue phosphor only blue, the triad, as a unit, is capable of producing an extended spectrum of color.

A second advantage of color comes from the contrast capability inherent in a color-shift, relative to that found with other techniques. Symbols, for example, offer a wider dynamic range than color, yet a small red spot in a field of blue is more quickly identified than an equally small circle in a field of triangles. This contrast effect defines more precisely for the operator the thresholds important in the detection of potential targets. Thus, in a DIMUS type display, intensity level 3 of the eight intensity levels may represent a range of certainty extending only from level 2 to level 4 whereas no confusion or ambiguity exists between levels 2, 3, and 4 if they are coded as red, green, and yellow (or any three distinguishable colors). The noise inherent in the noisy receiver (the operator) is thus reduced since ambiguity between perceptual units has been reduced.

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* J. B. Feallock, et al., "Absolute Judgement of Colors in the Federal Standards System," J. App. Psychol., 50, 266-272, June, 1966.

A third, and equally important, attribute of color is its compatibility with other techniques. Although it is itself a dimension of information transfer, color can be viewed as an additional dimension which can be superimposed on any other mode of information transfer, increasing the output and efficiency of the transfer process.

2. TASK STATEMENT

2.1 GENERAL

This study was designed to assess the use and value of color as a sonar display parameter.

2.2 SPECIFIC

The specific task of this program was to simulate a DIMUS sonar display and to determine if detection performance was influenced by the encoding of amplitude information in color as compared to the encoding of such information as brightness along a conventional grey scale.

3. METHOD

3.1 INSTRUMENTATION

The assessment of color as a sonar display parameter was accomplished with the use of the Color Display System designed by and developed at TRACOR, Inc.* The Color Display System consists of a standard color television receiver fed by a core memory through a control system. The core memory is updated by a digital tape transport. Figure 1 is a block diagram of the general system.

3.1.1 CRT

A standard color television receiver was used because it contained many of the circuits necessary for such a display and, in addition, was readily available. A circular faced CRT (type 21FJP22A CRT) was chosen because it exhibits less distortion than one with a rectangular face. Detailed specifications are contained in RCA Electron Tube Handbook HB 3.

The receiver used is a Zenith chassis (24MC32Z) selected because it is handwired and thus more easily modified. Detailed specifications are contained in Zenith Service Manual CM-108.

3.1.2 Core Memory

The core memory is a Fabri-Tek Model MSA-2 with a capacity of 4096 90-bit words. This particular core memory was chosen on the basis of word length, number of words and cycle time. Detailed specifications are contained in Fabri-Tek's Preliminary Instructions for the MSA2-07-90-5-04 Core Memory System.

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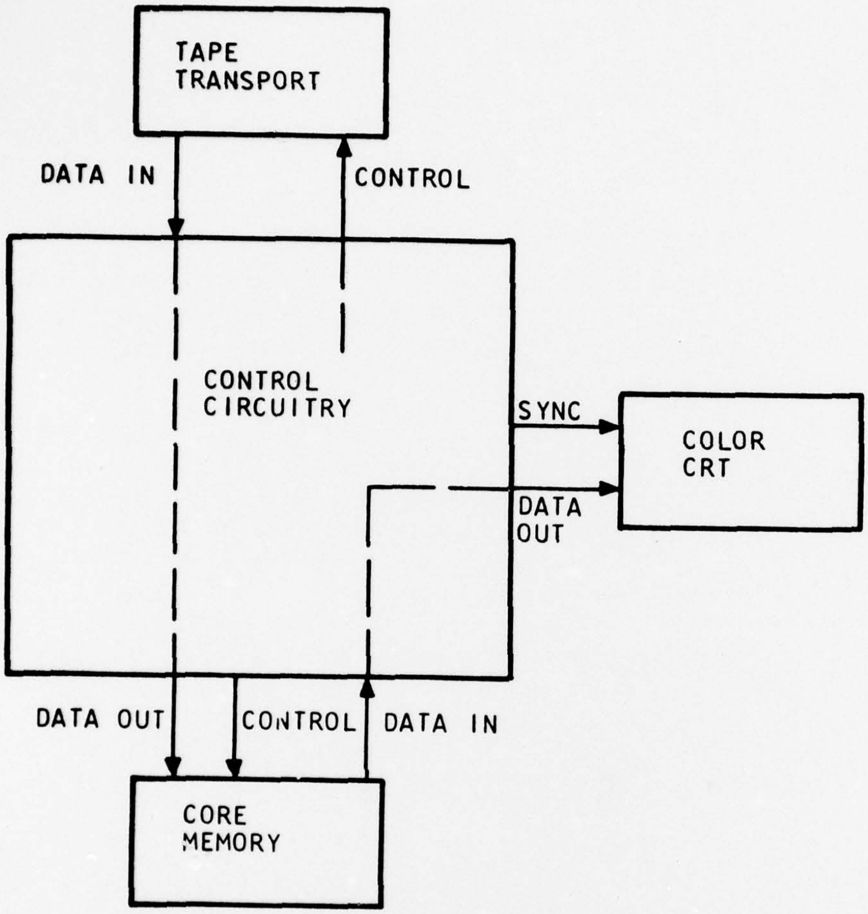
* For more detailed specification of the entire Color Display System refer to Summary Report, Design and Instrumentation of a Color Display for Sonar Information, TRACOR Document Number 67-473-U, 1967.



BASIC SYSTEM BLOCK DIAGRAM

3.1.3 Digital Tape Transport

The digital tape transport is a Control Data Corporation Model 9110B Digital Tape Transport. This particular tape transport was selected because of its high data rate and good reliability history. Detailed specifications are contained in Control Data 9110 Magnetic Tape Station Specifications 40805900-2.

3.1.4 Control Circuitry

The control circuitry was designed and constructed at TRACOR, Inc. The control circuitry performs three main functions:

(1) Information is taken from the tape transport, assembled into core memory language, and stored in the buffer shift register. The core memory is then loaded from the buffer shift register during blanking periods.

(2) Information stored in the core memory is extracted and displayed on the CRT according to a predetermined format.

(3) Synchronization signals are provided so that the display is stable and flicker free.

3.1.5 Response Device

Observers indicate their responses by means of a response "box" containing three controls. One control is a "read forward" push button which triggers the beginning of a trial. A second control is a "clear" push button which clears the screen of displayed data. The third control is a digital cursor provided by a hook generator and allows the observers to "point" to areas of interest on the CRT screen. The cursor symbol consists of two horizontal bars, at blanking levels, separated by an unblanked bar. Various points of the hook generator circuitry can be used to indicate to external circuitry (e.g., the electronic counters) the exact location of the hook.

Responses are recorded on electronic counters differentially "armed" to record the appropriate response.

3.2 PROCEDURE

Four male observers were used in a visual detection task in which they were required to determine the presence or absence of a target track in a simulated bearing-time visual display.

3.2.1 Display

The display format simulated a DIMUS sonar display with the exception that the "blanking" phenomenon observed in the DIMUS display was not incorporated into the simulated display. The exclusion of the "blanking" simplified software instrumentation and was justified by the fact that, at the signal-to-noise ratios used in this study, "blanking" would have been minimal, if present at all, on the actual DIMUS display.

The display was 12" vertically and 14" horizontally with 48 bearing "bins" horizontally displayed and 119 lines of information displayed vertically. The display was automatically updated every 1.75 seconds with a new line of information added to the top of the display and old information dropped from the bottom of the display. A maximum of 119 updates was possible before the screen was automatically blanked and a new trial commenced.

The observer used an electronic cursor to indicate the bearing bin in which he judged a track to be present.

3.2.2 Input

Gaussian distributed noise (mean = 0.00V., S.D. = 0.11V.) was generated and the amplitudes of the noise were digitized. A random number generator selected the particular digit to be assigned to any one bearing bin in any one line of information. Consequently the initial display (i.e., 48 bearing bins X 119 lines)

contained 5712 randomly selected digits with 48 new digits being added and 48 "old" digits being dropped with each update.

The complete distribution of digitized amplitudes was thresholded such that a particular range of digits was characterized by one intensity level of grey or by one color. The first threshold was placed at the mean of the noise distribution so that values of noise or signal plus noise which fell below the mean were assigned the intensity level (or color) corresponding to black. Consequently, in the noise-alone configuration there was a 50% marking density. The remaining thresholds were placed at equal fractions of standard deviation units above the mean of the noise distribution.

Both 3-bit and 4-bit display formats were used. In the 3-bit format, 8 levels of grey were used in the black-and-white display and 8 colors were used in the color display. With the exception of the first (located at the mean), the thresholds were placed at equal increments of 0.416 S.D. The last threshold was placed at 2.5 S.D.

In the 4-bit format, 16 colors were used. The thresholds were placed at equal increments of 0.214 S.D. with the first threshold placed at the mean and the last placed at 3.0 S.D.

A signal was presented in a particular bearing bin by adding a constant digital value, corresponding to the voltage increase necessary to obtain a desired signal-to-noise ratio, to the digitized distribution.

The color output on the CRT was determined by the sum of the intensity levels of all three color guns of the tri-phosphor shadow mask television CRT. Each color gun had 3 bits associated with it. Since these bits, (which determine the intensity level of a particular gun), could take any values from 000 to 111, 512 colors and 8 shades of grey were available.

3.2.3 Experimental Design

Six color conditions were investigated. One condition (c_0) was the black-and-white format, with a scale of grey ranging from black to white. Conditions c_I, c_{II}, c_{III}, and c_{IV} were 3-bit color formats consisting of various 8-color combinations of the 512 colors available. Condition c_V, the sixth condition, was a 4-bit, 16-color format.*

Various signal-to-noise ratios were used. Conditions c_0 and c_I, were investigated using -1, -3, -5, -7, and -9 dB signal-to-noise ratios. Conditions c_{II} through c_V were investigated at -2, -5, and -9 dB signal-to-noise ratios.

An average of 80 trials were run at each signal-to-noise level within each color condition. Approximately one-half of the 80 trials contained a signal (i.e., P(signal) = 0.50). A trial began with the initial picture (noise alone) and continued, automatically updating, until either the observer made a response or 119 updates had taken place. The screen was then blanked and a new trial initiated.

3.2.4 Observers

Four trained, male, psychophysical observers were used in this study. Prior to the actual recording of data, practice trials (using both color and black and white) were conducted for a number of days to eliminate any practice effects which may have arisen. During these practice trials, feedback concerning the correctness of their responses was given the observers. No feedback was given during the experimental trials.

The observers were instructed to indicate their decision concerning a track by placing the cursor over the appropriate

---

* The actual color values of c_0, c_I, c_{II}, c_{III}, c_{IV}, and c_V are contained in Appendix A.

bearing bin and pushing the "clear" to "stop" button when they judged a track to be present or by allowing the screen to update completely when they judged no track to be present.

Each subject received 20 trials at each signal-to-noise level within each color condition.

3.2.5 Analysis

Results were analyzed within the framework of the Theory of Signal Detectability (TSD). However, owing to the necessary simulation of an actual display, a response alternative is encountered which must be analyzed cautiously when using conventional TSD descriptive statistics. This "unique" alternative is illustrated in the response matrix below.

	Noise	Signal + Noise
No	A Correct Rejection	B Miss
Yes	C False Alarm	D Hit

	Signal + Noise
Yes	E

In addition to the four response alternatives possible in a binary decision task, a fifth response alternative, E, was possible in which the observer responded "Yes" when a target was

present but his response, as indicated by the position of the cursor, was to an event in a bearing bin other than the one in which the target was actually present.

Various alternative methods of dealing with this response can be conceptualized. However, the treatment of this response as a miss, i.e., as part of the [1.00 - P(hit)] quantity, satisfied the probabilistic relationships between response alternatives inherent in d′ analysis. Considered as a miss, the conditional dependency of B (miss) and D (hit) is maintained since D and E are themselves conditionally dependent. At the same time, the conditional independency of C (false alarm) and D is maintained. The analyses reported reflect the treatment of response alternative E as a miss, i.e., $P(D) = 1.00 - [P(B) + P(E)]$.

Two signal-to-noise ratios, -5 dB and -9 dB, were chosen for specific and detailed analysis.

4. RESULTS

The results are presented in Figs. 2 through 17.

Figure 2 represents the mean number of updates required to detect the target at various signal-to-noise ratios* for the six color conditions.

Figure 3 represents an analysis of regression using the method of least squared differences applied to the experimental data. The regression lines relate the number of updates to detection as a function of signal-to-noise ratio for the six color conditions.

Figure 4 represents the probability of detection for a false alarm probability of 0.10 at -5 dB and -9 dB signal-to-noise ratios for the six color conditions.

Figure 5 presents a weighted relationship between updates required to detect the target at -5 dB and -9 dB signal-to-noise ratios and the six color conditions. Since the means expressed in Fig. 2 do not reflect differences in the probability of a "hit," an arbitrary method of weighting the means to take into account possible differences in the probability of detection was used. By dividing the mean number of updates for each condition by the probability of detection X 100 associated with it for a constant false alarm rate (P[FA] = 0.10), a value expressing the number of updates required for a conditional probability of a hit of 0.01 is obtained. By multiplying this value by 100, a projection to the number of updates required for a 1.00 probability of

---

* Signal-to-noise ratio is defined as 20 $\log_{10} \frac{M_N - M_{SN}}{SD_N}$ where M_N is the mean voltage of the noise, M_{SN} is the mean voltage of signal plus noise and SD_N is the standard deviation in volts of the noise.

a hit is possible. Stated somewhat differently, the values plotted in Fig. 5 were arrived at by determining the percentage of the total number of updates available (119) required to detect the signal 100% of the time as determined by the observed percentage of updates required to achieve the percentage of hits observed.

Figures 6 through 11 present ROC curves for the various color conditions at -5 dB signal-to-noise ratio.

Figures 12 through 17 present ROC curves for the various color conditions at -9 dB signal-to-noise ratio.

It must be noted, however, that the curves presented in Figs. 6 through 17 were statistically generated using the d′ values obtained from the empirically determined probabilities of a hit and of a false alarm for each condition. (The triangle on each curve represents the empirically determined point, while the circles represent statistically determined points.) The curves assume normality and homogeniety of variance as characteristic of the underlying distributions of noise and signal plus noise and further assume that the shapes of the underlying distributions are the same for color as for black and white detection.

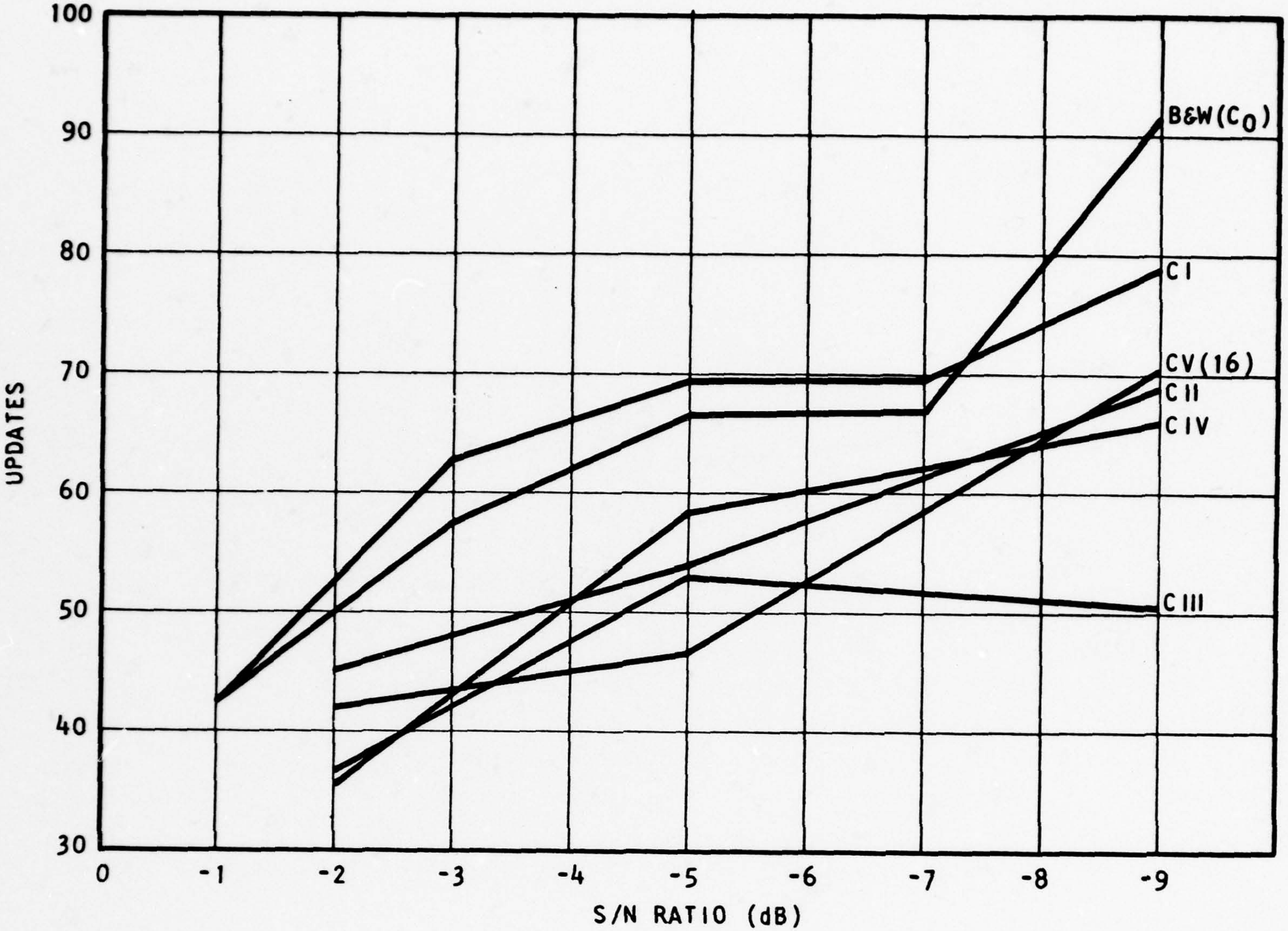


FIG. 2 - MEAN NUMBER OF UPDATES TO DETECTION AS A FUNCTION OF SIGNAL-TO-NOISE RATIO

TRACOR DWG A6-113-12
6/26/68 EVANS

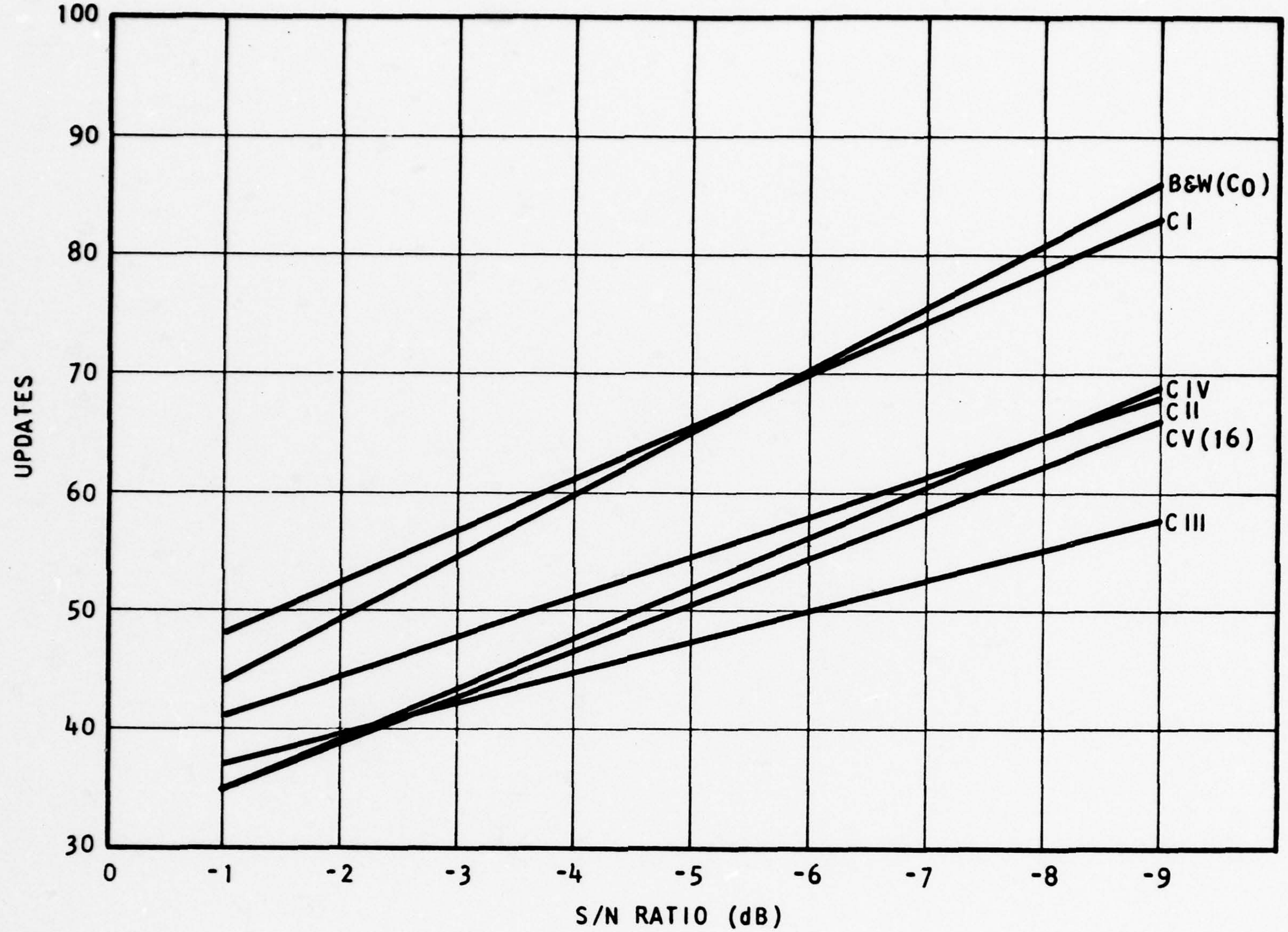


FIG. 3 - ANALYSIS OF REGRESSION RELATING UPDATES TO DETECTION AS A FUNCTION OF SIGNAL-TO-NOISE RATIO

TRACOR DWG. A6-113-13
8/26/68 EVANS

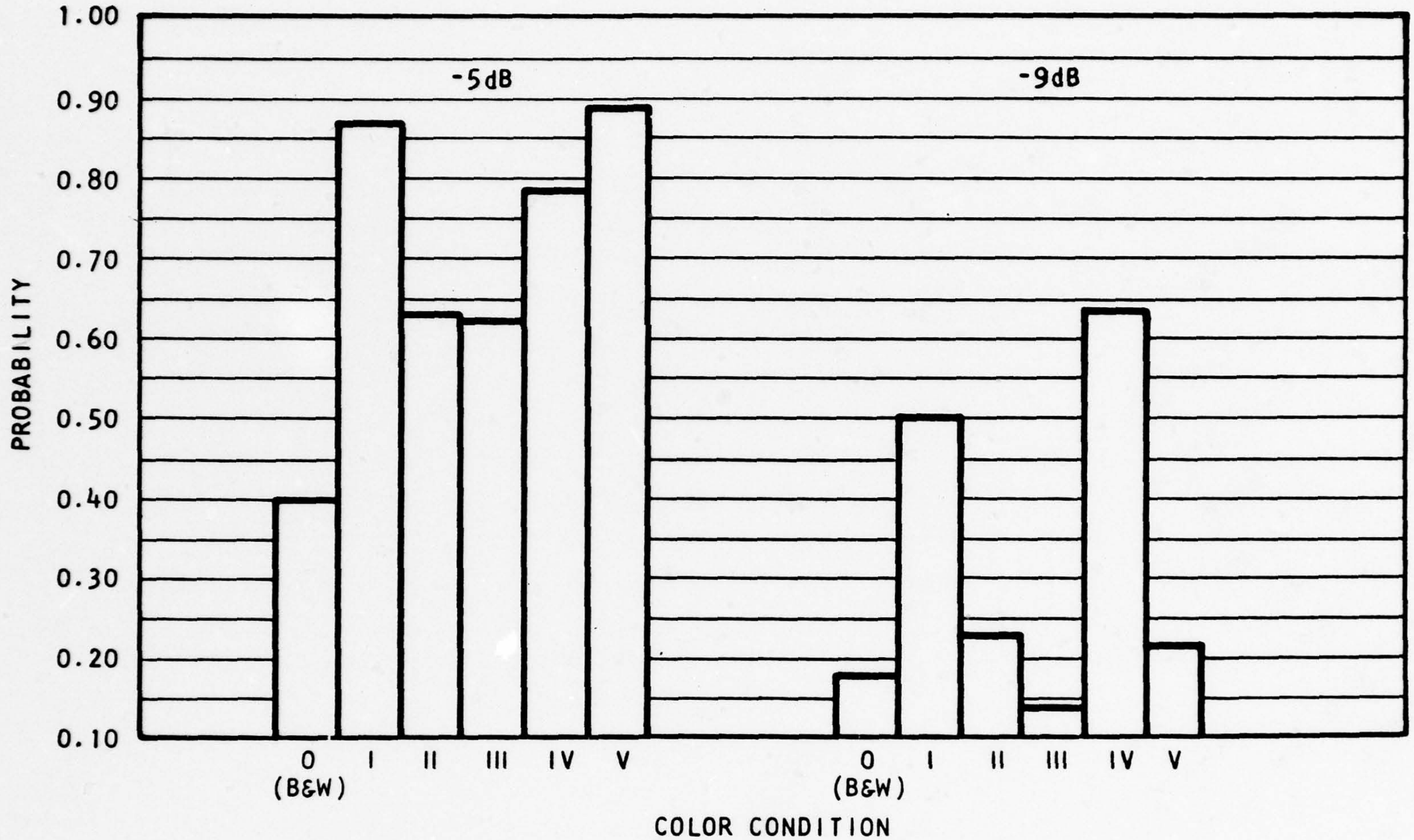


FIG. 4 - PROBABILITY OF DETECTION FOR A FALSE ALARM PROBABILITY OF 0.10

TRACOR DWG A6-113-13
6/25/68

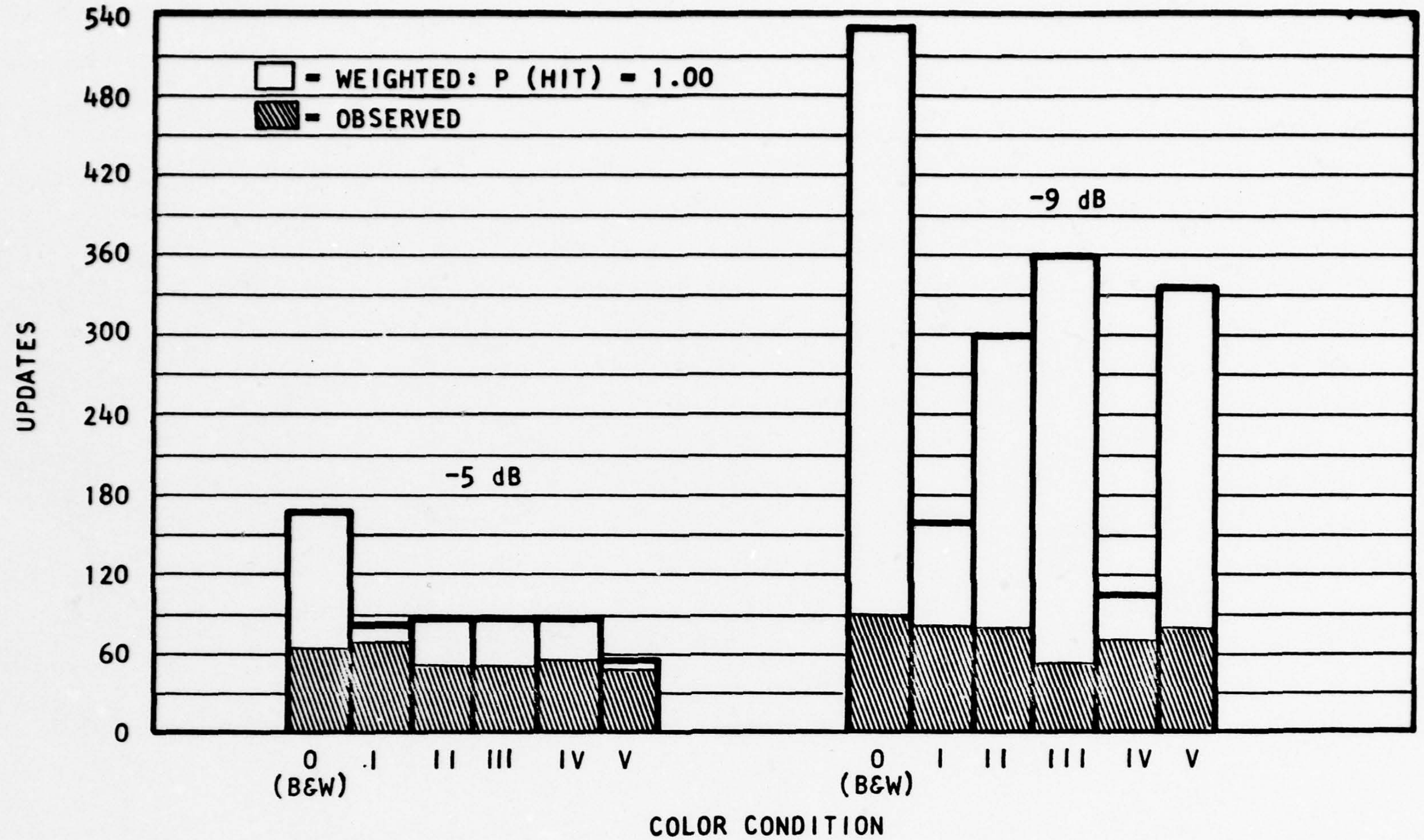


FIG. 5 - WEIGHTED AND OBSERVED UPDATES TO DETECTION

TRACOR DWG. A6-1/3
8/25/68
EVANS

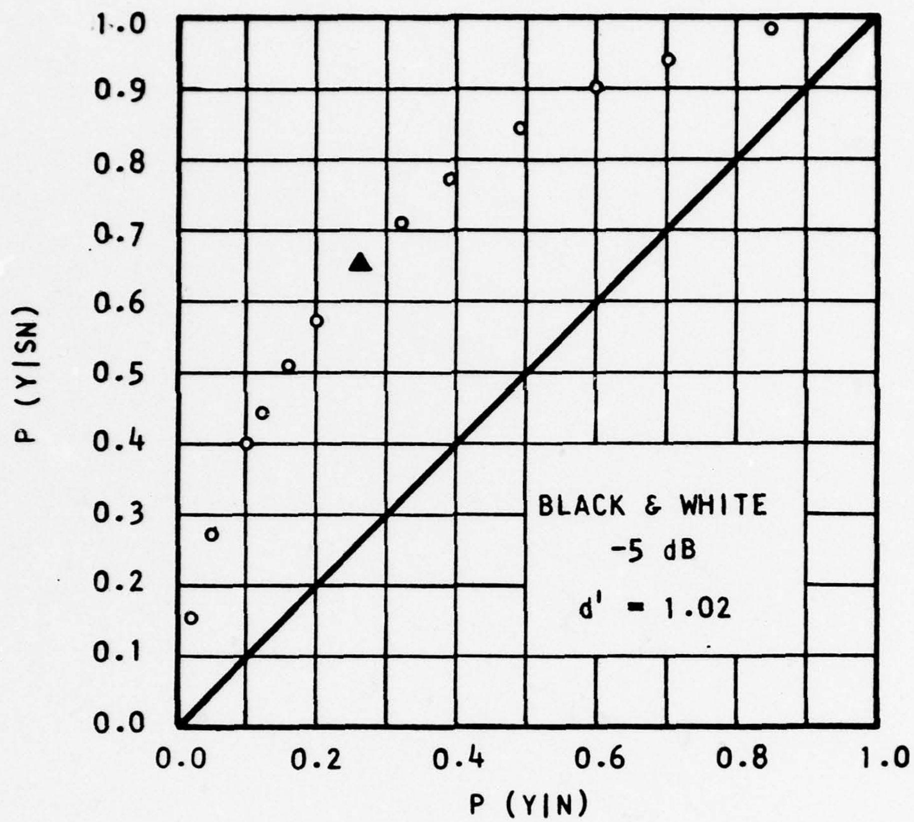


FIG. 6 - ROC CURVE, BLACK & WHITE, -5dB SIGNAL-TO-NOISE RATIO

TRACOR DWG A6-113

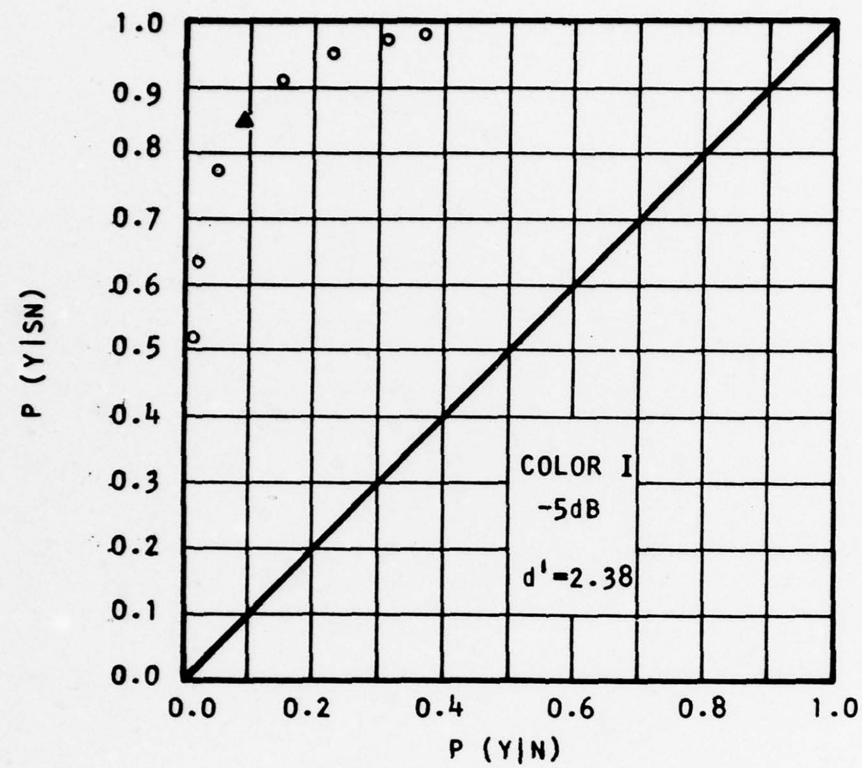


FIG. 7 - ROC CURVE, COLOR I, -5dB SIGNAL-TO-NOISE RATIO

TRACOR DWG. A6-113-17

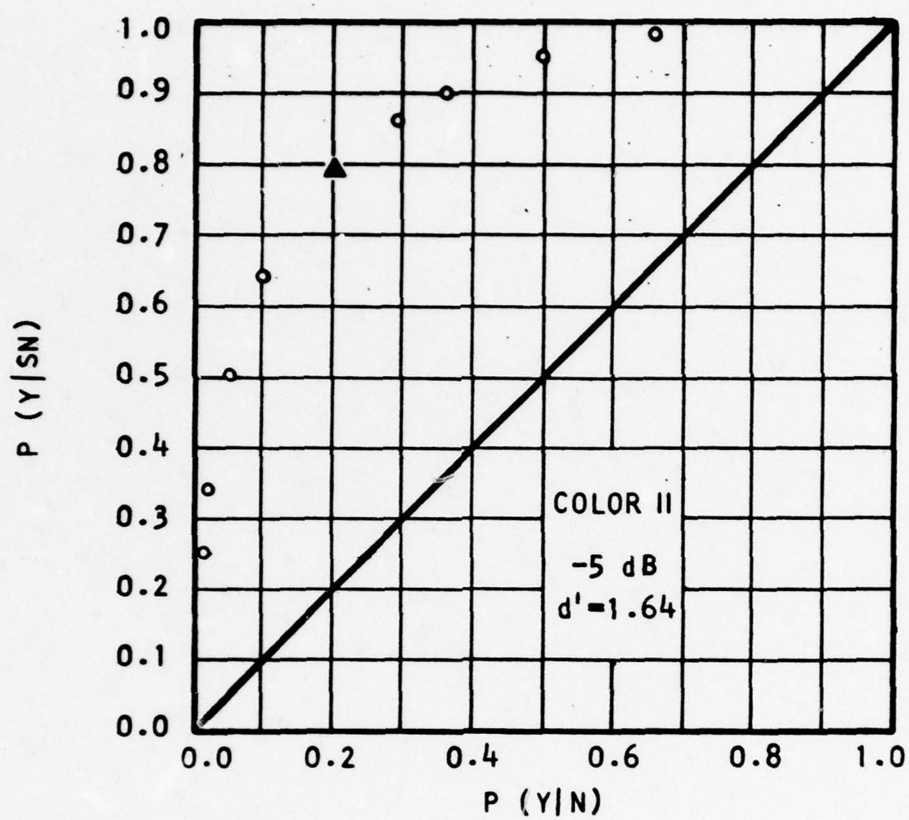


FIG. 8 - ROC CURVE, COLOR II, -5dB SIGNAL-TO-NOISE RATIO

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6/25/68 EVANS

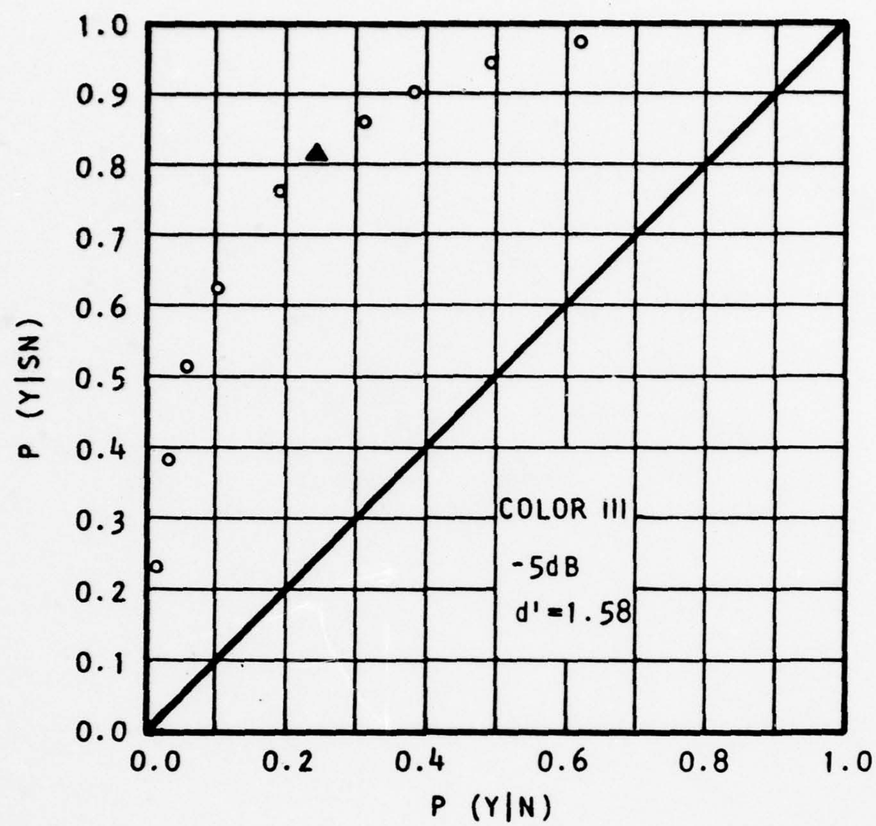

FIG. 9 - ROC CURVE, COLOR III, -5 dB SIGNAL-TO-NOISE RATIO

TRACOR DWG. A6-113-19

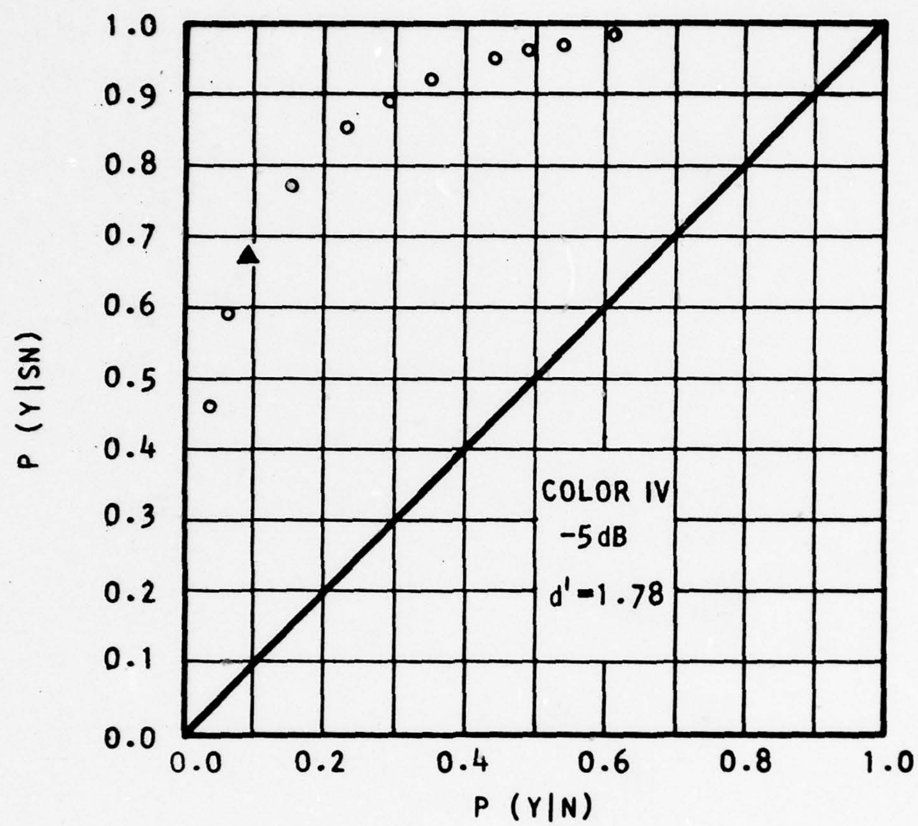

FIG. 10 - ROC CURVE, COLOR IV, -5dB SIGNAL-TO-NOISE RATIO

TRACOR DWG. A6-113-20

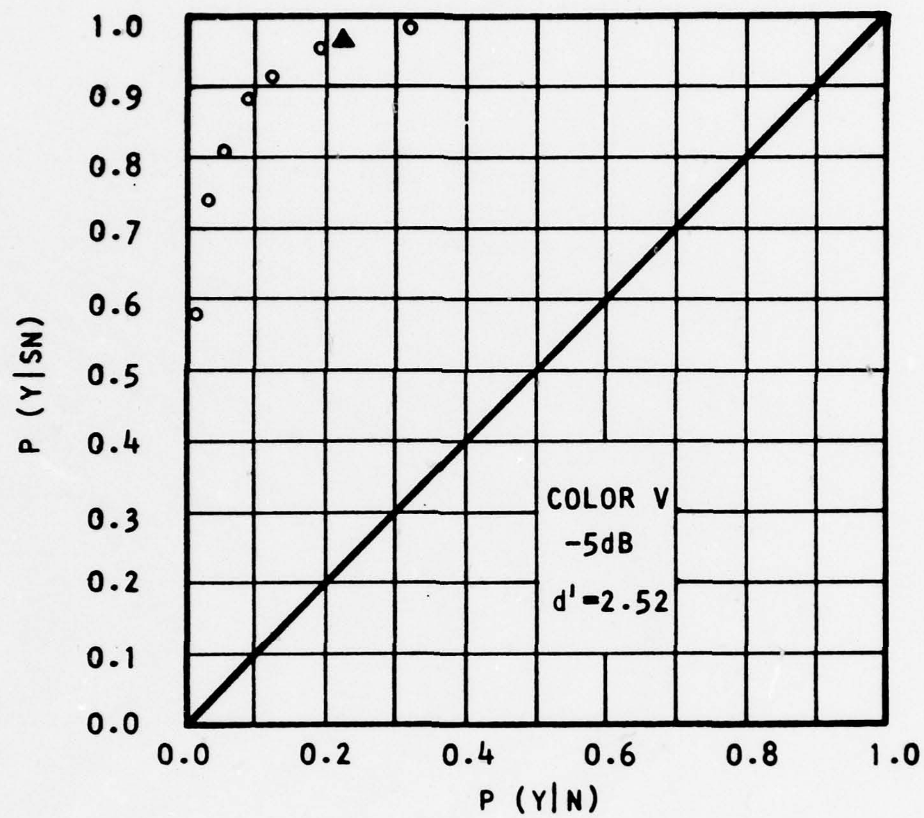

FIG. 11 - ROC CURVE, COLOR V, -5dB SIGNAL-TO-NOISE RATIO

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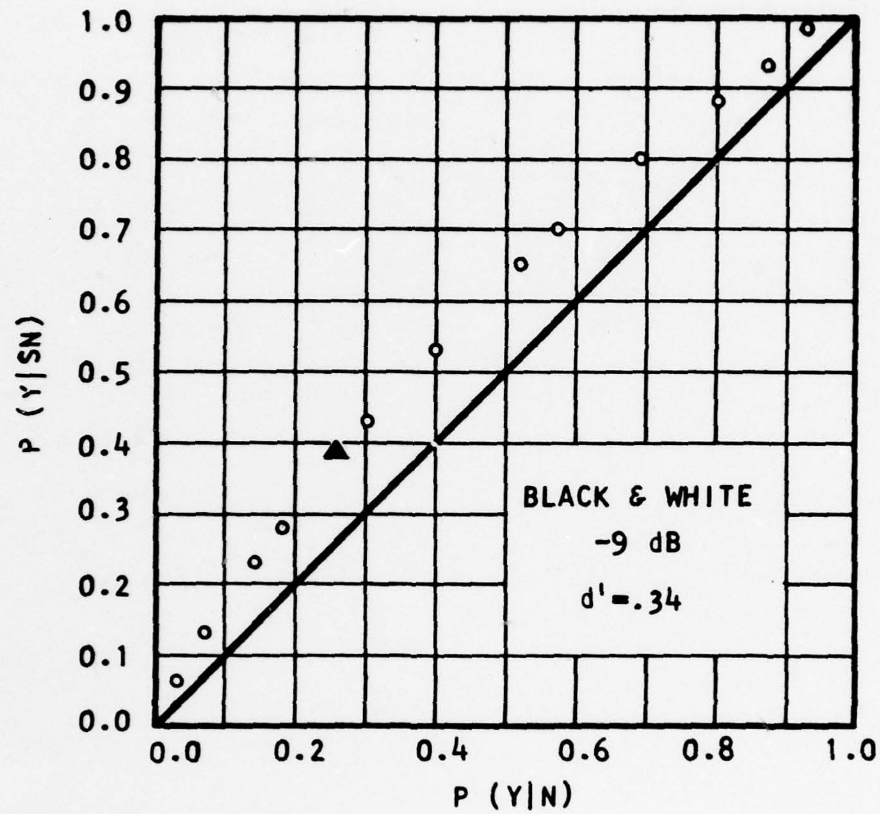

FIG. 12 - ROC CURVE, BLACK & WHITE, -9 dB SIGNAL-TO-NOISE RATIO

TRACOR DWG A6-113-22
6/25/68 EVANS

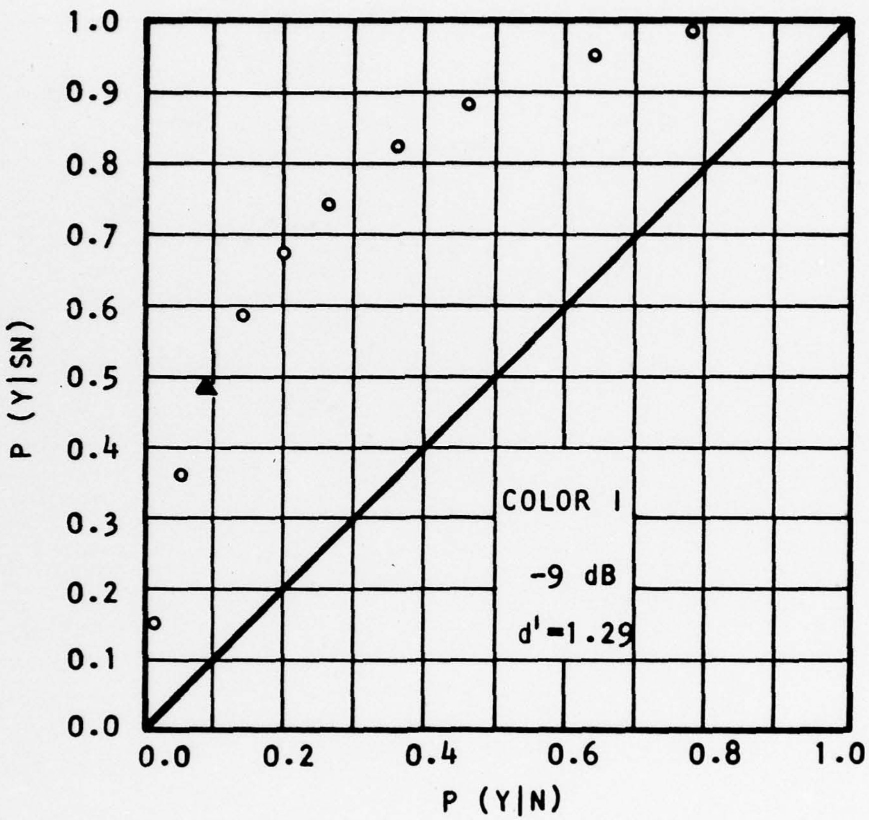

FIG. 13 - ROC CURVE, COLOR I, -9 dB SIGNAL-TO-NOISE RATIO

TRACOR DWG. A6-115-23
6/25/68 EVANS

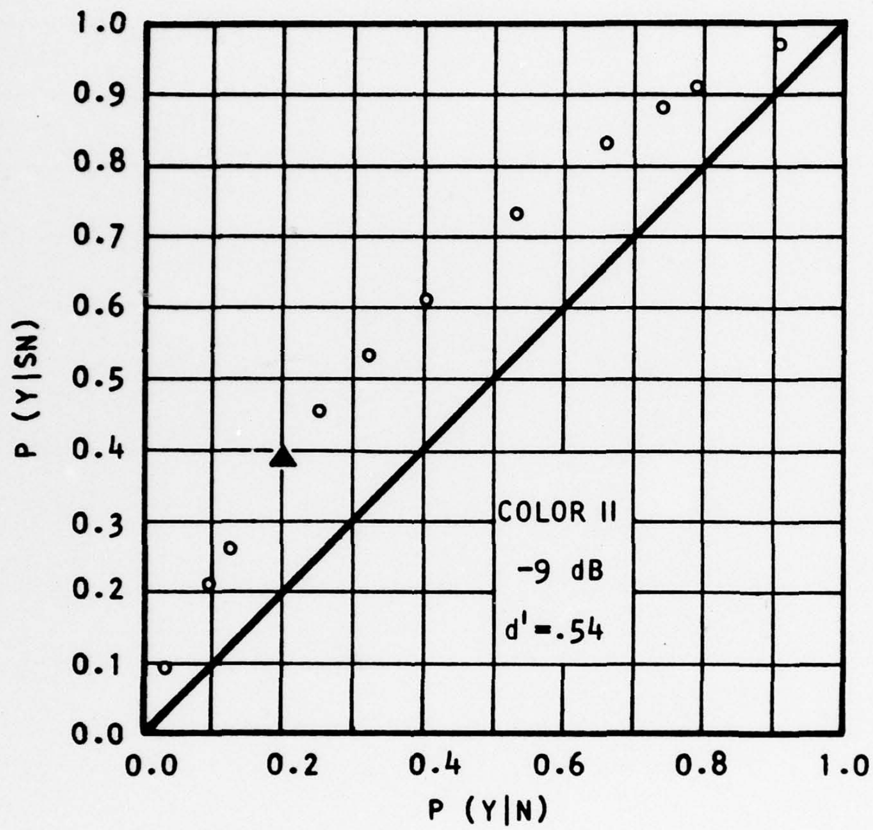

FIG. 14 - ROC CURVE, COLOR II, -9 dB SIGNAL-TO-NOISE RATIO

TRACOR DWG. A6-113-24

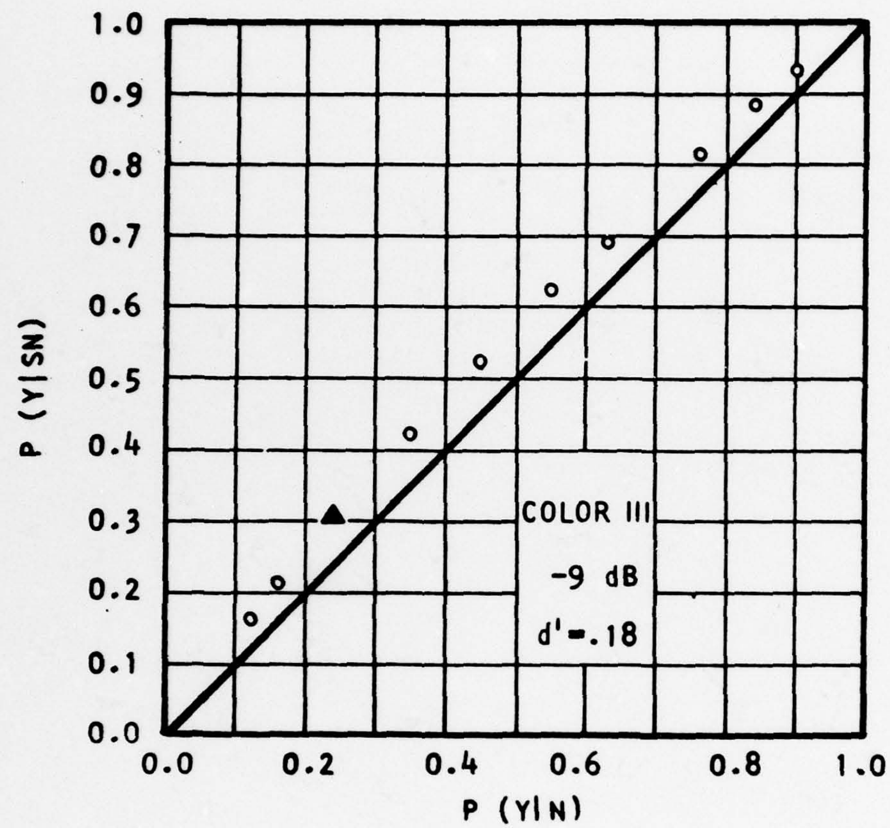

FIG. 15 - ROC CURVE, COLOR III, -9 dB SIGNAL-TO-NOISE RATIO

TRACOR DWG. A6-113-25

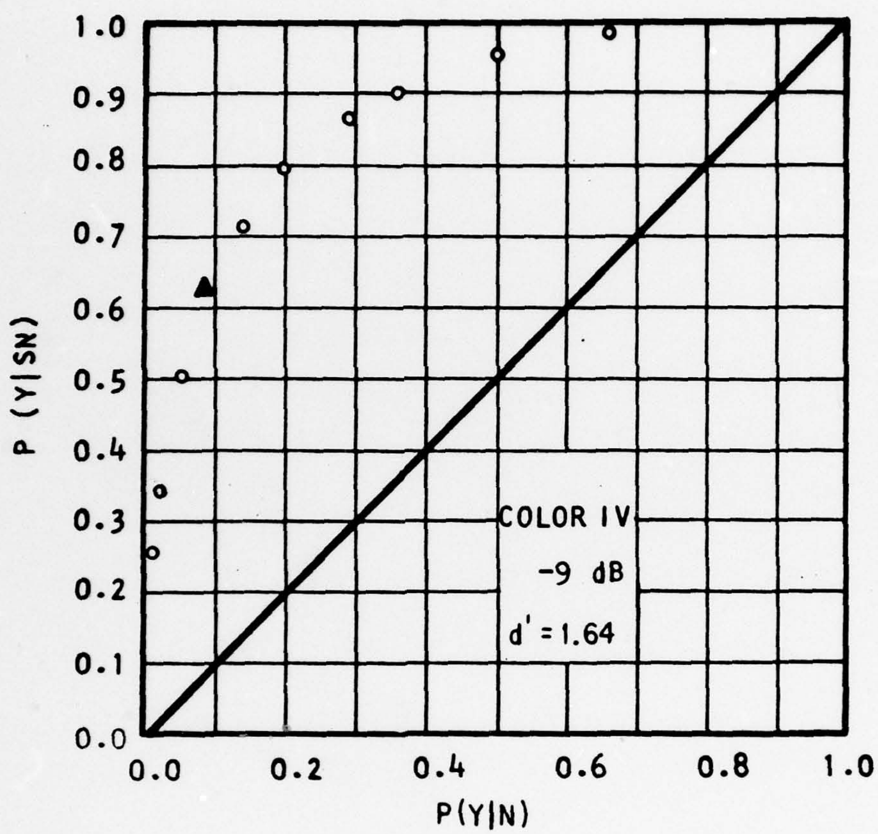

FIG. 16 - ROC CURVE, COLOR IV, -9 dB SIGNAL-TO-NOISE RATIO

TRACOR DWG. A6-113-2

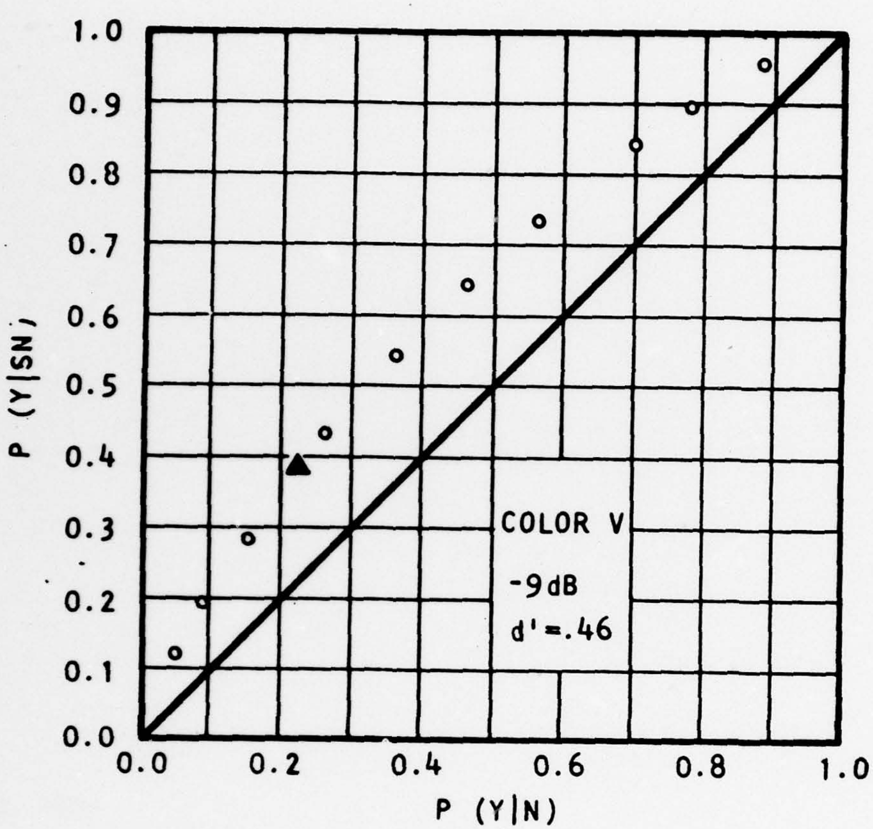

FIG. 17 - ROC CURVE, COLOR V, -9 dB SIGNAL-TO-NOISE RATIO

TRACOR DWG A6-... 6/25/68

5. DISCUSSION

5.1 DETECTION

Detection performance under the various color conditions can be evaluated by considering both the number of updates necessary to detect a target and the probability of detection for a given condition. As seen in Figs. 2 and 3, the mean number of updates required to detect a target under a particular condition is consistently less for color conditions c_{II}, c_{III}, c_{IV}, and c_V than for condition c_0, the black-and-white format. Condition c_I does not differ significantly from condition c_0 when compared only by updates to detection.

However, updates to detection for a given condition is a somewhat meaningless statistic unless evaluated along with the probability of detection for that condition. Using the detection probabilities associated with an arbitrary false alarm probability of 0.10 for each condition (Fig. 4), the resultant weighted values presented in Fig. 5 clearly demonstrate a superiority of all the color formats over the black-and-white format at the -5 dB and -9 dB levels--including the color series c_I.

5.2 DETECTABILITY INDEX, d′

Using the observed probabilities of a hit and a false alarm, an index of detectability, d′, can be calculated for each condition. Since, by definition, d′ defines the separation of the noise and signal plus noise distributions as perceived by the observers, knowledge of d′ permits the statistical generation of the Receiver Operating Characteristic (ROC) curve for that condition. Such curves are presented in Figs. 6 through 17.

However, unlike empirically determined ROC curves, the shapes of which are determined by actual changes in the observer's response criterion, statistically generated curves require certain

assumptions. One of these assumptions is that the shapes of the underlying distributions of noise and signal plus noise are known or at least not greatly different from some assumed shapes. The curves presented were generated under the assumptions that the underlying distributions were normal and of equal variance. Violation of these assumptions is not of any consequence when comparing relative differences if it can be assumed that the shapes of the underlying distributions are the same for the two conditions being compared. This latter assumption has also been made.

Examination of the ROC curves at -5 dB signal-to-noise ratio reveals that the color formats result in greater detectability than the black-and-white format without exception. The d′ value associated with the black-and-white format is 1.02. Color_{III}, with d′ = 1.58, evidences the lowest d′ value of the color formats at this signal-to-noise ratio but this value is still significantly greater than that associated with the black-and-white format.

At a -9 dB signal-to-noise ratio, the only color format which evidences lower detectability than the black-and-white format is c_{III}. Whereas black-and-white yields an average d′ of 0.34, c_{III} yields an average of 0.18. At d′ values of such small magnitudes, however, the significance of such a difference is difficult to appraise. In contrast, color c_{IV} shows a d′ value of 1.64--a value which is significantly higher than that evidenced by the black-and-white format at the -5 dB signal-to-noise ratio.

6. CONCLUSIONS

From the results of this study of color as a sonar display parameter, it is concluded that the use of color for encoding of amplitude information significantly increases the detectability of target tracks of the nature presented. This increase in detectability is in excess of 4 dB in the case of color c_{IV} (i.e., detectability under c_{IV} is greater at -9 dB signal-to-noise ratio than is detectability under the black-and-white condition at -5 dB signal-to-noise ratio) as compared to black and white.

7. RECOMMENDATIONS

In spite of the general superiority of all the color formats over the black-and-white format, recommendation of a specific color format is necessary for potential specification of possible future sonar modifications.

Based on the number of updates required to detect a target and on the probability of such detection, it is recommended that color format c_{IV} be considered as an exemplary format for the use of color as a sonar display parameter when only eight levels are used.

Although two of the other color formats evidence greater detectability at -5 dB signal-to-noise ratio than format c_{IV}, the latter evidences the greatest detectability as well as the least decrement in detectability (compared to -5 dB) at the -9 dB level. Similarly, in terms of updates to detection, C_{IV} is distinguishable as the best of the colors considered at a -9 dB signal-to-noise ratio.

APPENDIX A: EXPERIMENTAL COLOR FORMATS

The color output on the CRT was determined by the sum of the intensity levels of all three color guns of the television CRT used. Each color gun was driven by 3 bits of data on level. Since these bits could take any values from 000 to 111, 512 colors and 8 shades of grey were available. The following tables present the actual colors used for the color conditions c_0, c_I, c_{II}, c_{III}, c_{IV}, and c_V. The numbers (1 through 8 or 1 through 16) located vertically along the margins of the color cells represent the colors (either 8 or 16) used in the format, the number 1 representing the color associated with the weakest noise event and the highest number representing the color associated with the strongest noise event.

Within each cell, the numbers 0 through 7 represent the relative level of color contributed by each of the three color guns of the CRT, 0 representing no color at all (i.e., 000) and 7 representing the highest level (i.e., 111).

A.1 BLACK AND WHITE (c_0)

	Red	Blue	Green
1	0	0	0
2	1	1	1
3	2	2	2
4	3	3	3
5	4	4	4
6	5	5	5
7	6	6	6
8	7	7	7

A.2 COLOR I

	Red	Blue	Green
1	0	0	0
2	0	3	0
3	0	5	0
4	0	7	0
5	7	0	0
6	0	0	5
7	7	0	7
8	7	7	7

A.3 COLOR II

	Red	Blue	Green
1	0	0	0
2	0	0	2
3	0	2	4
4	1	7	1
5	5	5	0
6	7	0	0
7	7	0	7
8	7	7	7

A.4 COLOR III

	Red	Blue	Green
1	0	0	0
2	1	3	0
3	2	3	3
4	3	0	2
5	3	1	4
6	5	2	5
7	6	4	4
8	7	6	6

A.5 COLOR IV

	Red	Blue	Green
1	0	0	0
2	0	5	2
3	1	2	4
4	2	0	5
5	3	4	2
6	5	5	2
7	7	4	1
8	7	1	3

A.6 COLOR V

	Red	Blue	Green
1	0	0	0
2	1	1	1
3	2	1	1
4	3	2	2
5	4	2	2
6	5	2	2
7	6	2	2
8	7	2	2
9	6	4	2
10	5	6	2
11	3	7	2
12	0	1	5
13	1	1	7
14	4	1	7
15	7	1	7
16	7	7	7

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1 ORIGINATING ACTIVITY (Corporate author) TRACOR, Inc., 6500 Tracor Lane, Austin, Texas 78721	2a REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b GROUP

3 REPORT TITLE

SUMMARY REPORT ON THE ASSESSMENT OF COLOR AS A SONAR DISPLAY PARAMETER

4 DESCRIPTIVE NOTES (Type of report and inclusive dates)

Summary Report

5 AUTHOR(S) (Last name, first name, initial)

Evans, Thomas R.

6 REPORT DATE	7a TOTAL NO. OF PAGES	7b NO. OF REFS
25 June 1968	38	2

8a CONTRACT OR GRANT NO. N00024-67-C-1461 b. PROJECT NO. 002-039-01 c d	9a. ORIGINATOR'S REPORT NUMBER(S) 68-766-U 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

DISTRIBUTION STATEMENT A

Approved for public release; Distribution Unlimited

Department of the Navy
Naval Ship Systems Command
Washington, D. C. 20360

13 ABSTRACT

This study was designed to assess the use and value of color as a sonar display parameter. A DIMUS sonar display was simulated and detection performance as influenced by the encoding of amplitude information in color as compared to the encoding of such information as brightness along a conventional grey scale was examined.

The color formats yielded significant increases in detection relative to detection using a black-and-white format.

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